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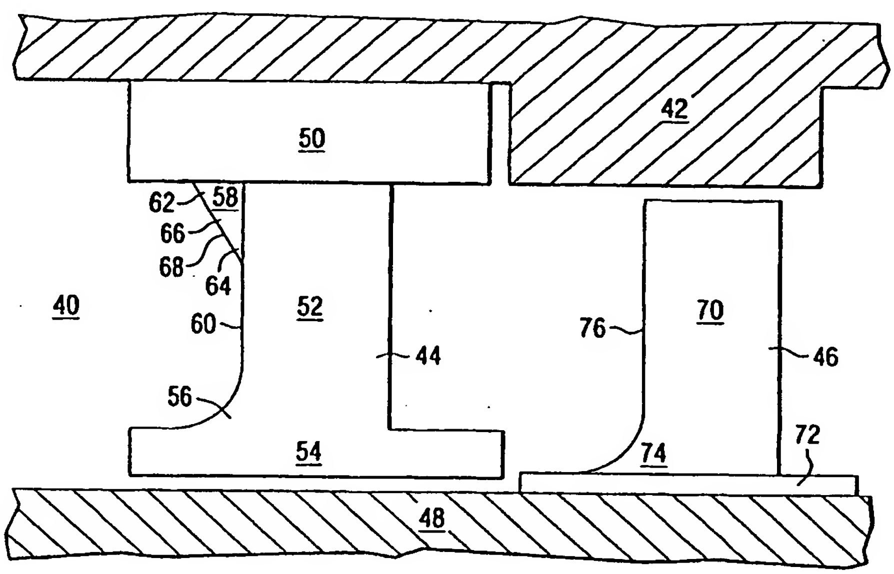

(57) Abstract

A turbo-machine (40) having a vortex elimination device (56, 58, 74) disposed at the intersection of a blade (46) or vane (44) and its end wall (50, 54, 72). The vortex elimination device (56, 58, 74) may have a generally triangular shape with a straight (58) or curvilinear (56) leading edge and may be formed to be integral (56, 74) with or attached to (58) the airfoil (52, 70) and endwall (50, 54, 72). The vortex elimination device prevents the formation of a leading edge horseshoe vortex as the flow stream passes over the leading edge of the airfoil by generating a radial leading edge force that counters the radial equilibrium and stagnated flow forces, thereby providing a smooth flow stream around the airfoil leading edge.

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AIRFOIL LEADING EDGE VORTEX ELIMINATION DEVICE

This invention was made with United States Government support under contract number DE-FC21-95MC32267 awarded by the Department of Energy. The Government has certain rights in this invention.

FIELD OF THE INVENTION

The present invention relates generally to turbo-machines and more particularly to a device for eliminating leading edge horseshoe vortexes that occur in turbo-machines at the intersection of the leading edge of airfoils with their respective end walls.

BACKGROUND OF THE INVENTION

Generally, leading edge horseshoe vortex refers to a secondary flow phenomenon which develops in a turbo-machine at the intersection of the leading edge of a blade with an end wall. As used herein, the term turbo-machine is meant to include gas or combustion turbines, compressors, steam turbines and similar rotating hydro-dynamic machines. The term blade is meant to include both stationary components, sometimes referred to as vanes, and rotating components, sometimes referred to as blades. The term end wall is meant to include the platform near the root of a rotating blade, the hub at the fixed end of a stationary vane, and the shroud at the free end of a stationary vane.

Figure 1 provides a perspective view of a portion of a turbo-machine, in this case a combustion turbine 10. The figure illustrates the flow of gases 12 at the intersection of a blade 14 and end wall 16 of a prior art turbo-machine 10. Figure 1 illustrates a portion of a

the leading edge of the turbine blade. The radial equilibrium pressure forces are radial and are directed toward the endwall. The centrifugal forces are radial and are directed away from the endwall. The leading edge of the turbine blade exerts a force equal and opposite to the axial component of the stagnated flow forces. The resultant vector of these forces is a force toward the endwall. It is this resultant force which drives the stagnated flow radially inward along the leading edge and back upstream along the end wall, thereby creating the leading edge horseshoe vectors shown in Figure 1. Although Figure 1 illustrates only a rotating blade and platform, similar forces may combine at the intersection of a stationary airfoil and its endwall at either the hub and tip end, and vortexes may be generated at these locations under appropriate conditions.

Prior art blade designs have attempted to control and diffuse the formation of the LEHV, but they do not prevent the LEHV from forming. Known mechanisms for controlling or diffusing the LEHV are airfoil leaning, bowing, count changes and re-distributions of inlet swirl angle. Controlling and diffusing the LEHV, however has the effect of increasing losses by increasing viscous mixing and secondary flows. It is therefore desirable to provide a means for preventing a leading edge horseshoe vortex from developing so as to prevent the inefficiencies associated with such a phenomenon.

SUMMARY OF THE INVENTION

Accordingly, it is the general object of the current invention to provide a blade for a turbo-machine which will not generate a leading edge horseshoe vortex. It is a further object of this invention to provide a

turbo-machine designed to achieve the high efficiency of modern turbine engines with an advanced airfoil design that will minimize or eliminate the generation of leading edge horseshoe vortexes. Briefly, these and other objects of the current invention, are accomplished by a blade for use in a turbo-machine having an airfoil section having a leading edge, an endwall attached to an end of said airfoil section, and a vortex elimination device disposed between the endwall and the leading edge. A turbo-machine in accordance with this invention has an airfoil having a leading edge disposed in a flow stream passing through said turbo-machine; an endwall disposed adjacent an end of the airfoil, the flow stream passing along the endwall and over the leading edge; the flow stream through the turbo-machine and over the leading edge generating a stagnated flow force, a radial equilibrium force, a centrifugal force, and a leading edge force; a means for generating a radial vector in the leading edge force of sufficient magnitude to prevent the creation of a horse-shoe vortex in the flow stream as it passes over the leading edge, the generating means being disposed at the intersection of the leading edge and the endwall.

Additional features and advantages of the present invention will become evident hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of the preferred embodiment, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there is shown in the drawings embodiments that are presently preferred, it being understood,

however, that the invention is not limited to the specific methods and instrumentalities disclosed.

Figure 1 is a perspective view of a portion of a row of prior art blades attached to a rotor of a combustion turbine.

Figure 2 is a diagram of the forces acting on the gas flow stream near the intersection of the blade and end wall of Figure 1.

Figure 3 is a perspective view of a combustion turbine blade incorporating a vortex elimination device in accordance with the invention.

Figure 4 illustrates a portion of the plurality of rows of rotating and stationary blades of a turbo-machine built in accordance with this invention having vortex elimination devices on both its stationary and rotating blades.

Figure 5 illustrates the flow stream near the intersection of a blade and endwall of a prior art turbo-machine.

Figure 6 illustrates the flow stream near the intersection of a blade and endwall of a turbo-machine built in accordance with this invention.

Figure 7 is a diagram of the forces acting on the gas flow stream near the intersection of the blade and end wall of a turbo-machine built in accordance with this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides a turbo-machine having a blade that incorporates a vortex elimination device formed to be integral with or appended to the blade so as to cancel or to overcome the resultant radial force acting on the flow stream passing over the blade at

the intersection of the blade leading edge with the endwall. The device of the present invention eliminates or reduces the LEHV by countering the airfoil leading edge surface radial pressure gradient produced by the inlet swirl velocity and the endwall boundary layers. The device eliminates or reduces the LEHV by directing the flow stream to travel in an organized manner about the leading edge of the airfoil. The vortex elimination device is contoured so as to direct the incoming flow in a direction that opposes the stagnated pressure gradient and prevents stagnated flow from migrating upstream to cause a vortex. The angle of the leading edge surface of the vortex elimination device is selected to be proportional to the stagnated radial pressure gradient so as to result in minimized or eliminated radial flow.

Figure 3 provides a perspective view of a combustion turbine blade 24 that incorporates a vortex elimination device 26. The embodiment of Figure 3 includes a blade 24 having a root 28 operable to be inserted into openings in a rotor (not shown), a platform 30 that functions as an endwall, and an airfoil 32. Appended to or formed as an integral part of the blade 24 is a vortex elimination device 26. As shown, the vortex elimination device 26 is placed at the intersection of the turbine blade leading edge 34 with the endwall 30. The angle of intersection between the vortex elimination device 26 and the end wall 30 is greater than 90 degrees. This is in contrast to the turbine blade of Figure 1 wherein the leading edge intersected the endwall at a nearly perpendicular angle. The angled slope of the leading edge 36 of the vortex elimination device 26 provides a radial pressure in a direction away from the endwall 30 on a flow stream (not shown) passing over the airfoil 32. This radial pressure

will oppose the downward resultant force described above with reference to Figures 1 and 2.

Figure 4 is a sectional view of a turbo-machine 40 built in accordance with this invention. The turbo-machine has a cylinder 42 and a plurality of rows of stationary vanes 44 attached to the cylinder 42, and a plurality of rows of rotating blades 46 attached to a rotor 48 and interspersed between the rows of stationary vanes 44, as is known in the art. The stationary vane 44 of Figure 4 has a hub 50, and airfoil 52, and a shroud 54. A first vortex elimination device 56 is formed to be integral with the airfoil 52 and the shroud 54. A second vortex elimination device 58 is formed as a separate device and is attached at the intersection of the hub 50 and the leading edge 60 of the airfoil 52. Each vortex elimination device 56,58 can be described as having a wedge-like shape that is angled between the inner 54 and/or outer 50 end wall and the leading edge 60 of the vane 44. The second vortex elimination device 58 comprises a first arm 62 appended to the hub and a second arm 64 appended to the leading edge 60 of the airfoil 52. A body 66 having a substantially wedge shape is formed between the first 62 and second 64 arm. The first arm 62 may typically be from 90-150 percent of the length of the second arm 64. The first arm 64 may typically extend the endwall chord length of the blade in the range of 10-35 percent. The leading edge 68 of the vortex elimination device 58 may be a straight line, thereby forming a vortex elimination device having a generally triangular shape, or it may be a curvilinear surface disposed between the endwall 50 and the airfoil 52. The curvilinear surface may be a parabolic shape or an elliptical shape, for example, blending smoothly into the

shape of the airfoil 52 and endwall 50. Of course, the geometry of the vortex elimination device varies depending upon the size of the airfoil 52 and the application for which it will be used.

A rotating blade 46 is also illustrated in Figure 4. This blade 46 has an airfoil 70 attached to a platform 72 that is attached to the rotor 48. A vortex elimination device 74, in this case formed to be integral with the airfoil 70, is disposed between the leading edge 76 of the airfoil 70 and the platform 72. Although Figure 4 illustrates three vortex elimination devices 56,58,74, the selection of location for these devices will be based upon the particular flow dynamics of the individual turbo-machine 40. It may be desirable in one embodiment to include a vortex elimination device with each of the blades of one or more of the plurality of rows of rotating blades. In another embodiment it may be desirable to include a vortex elimination device with each of the blades of one or more of the plurality of rows of stationary blades, at one or both ends of the stationary blades.

The formation of a LEHV is a three dimensional phenomenon and thus requires three-dimensional computational analysis. The vortex elimination device is designed by integrating or appending such a device to leading edge of airfoil. The turbo-machine system is then analyzed using any of the known three-dimensional fluid dynamics codes to determine the effectiveness of the selected design. Iterations between device configuration and fluid dynamics analysis will result in an optimal shape(s) and location(s) for the vortex elimination device(s). Full-scale performance tests have been conducted in a test facility to verify the performance of the inventive design. Test results demonstrate improved blade performance, a more uniform radial exit mass flow distribution, and a beneficial reduction in leading edge hub heat transfer. Figure 5 illustrates the flow stream 80 and resulting vortex 82 near the intersection of a prior art blade 84 and endwall 86. By contrast, Figure 6 illustrates the flow stream 90 near the intersection of a blade 92 and endwall 94 according to this invention. As shown in Figure 6, the gas flow is either directed around the airfoil and/or directed upward, away from the intersection of the blade 92 and the endwall 94. The angled vortex elimination device 96 operates to provide a force opposite to that of the stagnated flow force, thereby eliminating the horseshoe vortex associated with prior art blades.

Figure 7 provides an analysis of the forces resulting at the intersection of the inventive device with the inner endwall. As described above with reference to Figure 2, the stagnated flow is substantially axial but also has a radial component toward the endwall. Likewise, the radial equilibrium

pressure forces are directed toward the endwall while the radial centrifugal forces are directed away from the endwall. Unlike the prior art arrangement of Figure 2, however, the vortex elimination device provides a means for generating a radial vector in the leading edge force which is of sufficient magnitude to offset the radial components of the stagnated flow and radial equilibrium pressure forces, and therefore to prevent the creation of a horseshoe vortex in the flow stream as it passes over the leading edge of the airfoil. A turbo-machine having a vortex elimination device in accordance with the present invention will exhibit decreased aerodynamic losses through a row of blades than would a prior art device. Additionally, the present invention provides inlet conditions that are more uniform and stable for downstream rows of blades. Overall airfoil aerodynamic and cooling design is simplified because there is one less secondary flow component to be considered. Eliminating the stagnation vortex results in a lower heat transfer rate at the endwalls, which in turn results in a more efficient turbine due to the cooling air reduction. Further, the addition of the vortex elimination device provides for an improved mechanical connection between the endwall and blade.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. Accordingly, reference should be made to the appended claims, rather than to the foregoing specification, as indicating the scope of the invention.

CLAIMS

I claim as my invention:

1. A blade (44,46) for use in a turbo-machine (40) comprising:

an airfoil section (52,70) having a leading edge(60,76);

an endwall (50,54,72) attached to an end of said airfoil section (52,70);

a vortex elimination device (56,58,74) disposed between said endwall and said leading edge.

2. The blade of claim 1, wherein said vortex elimination device (56,74) is formed to be integral with said airfoil section (52,70).

3. The blade of claim 1, wherein said vortex elimination (56) device is formed to be integral with said endwall (54).

4. The blade of claim 1, wherein said vortex elimination device (56) is formed to be integral with said airfoil section (52) and with said endwall (54).

5. The blade of claim 1, wherein said vortex elimination device (56,74) further comprises a curvilinear surface disposed between said endwall and said leading edge.

6. The blade of claim 5, wherein said curvilinear surface comprises a parabolic shape.

7. The blade of claim 5, wherein said curvilinear surface comprises an elliptical shape.

8. The blade of claim 1, wherein said vortex elimination device (58) comprises a generally triangular shape.

9. A turbo-machine (40) having a cylinder (42); a rotor (48) disposed within said cylinder; a plurality of rows of blades (46) attached to said rotor, each of said blades having a platform (72) attached to said rotor (48), and an airfoil (70) having a leading edge (76) attached to said platform (72); a plurality of rows of vanes (60) attached to said cylinder (42) and interspersed between said rows of blades (46); characterized by a vortex elimination device (74) disposed at the intersection of said platform (72) and said leading edge (76) of said airfoil (70) of each of the blades (46) of at least one of said rows of blades.

10. A turbo-machine (40) having a cylinder (42); a rotor (48) disposed within said cylinder; a plurality of rows of blades (46) attached to said rotor; a plurality of rows of vanes (44) attached to said cylinder (42) and interspersed between said rows of blades (46), each of said vanes (44) having a hub (50) attached to said cylinder (42), an airfoil (52) having a leading edge (60) attached to said hub (50); characterized by a vortex elimination device (58) disposed at the intersection of said hub (50) and said leading edge (60) of said airfoil (52) of each of the vanes (44) of at least one of said rows of vanes.

11. A turbo-machine (40) having a cylinder (42); a rotor (48) disposed within said cylinder (42) ; a plurality of rows of blades (46) attached to said rotor

(48); a plurality of rows of vanes (44) attached to said cylinder (42) and interspersed between said rows of blades (46), each of said vanes (44) having a hub (50) attached to said cylinder (42), an airfoil (52) having a leading edge (60) attached to said hub (42), and a shroud (54) attached to said airfoil (60); characterized by a vortex elimination device (56) disposed at the intersection of said shroud (54) and said leading edge (60) of said airfoil (52) of each of the vanes (44) of at least one of said rows of vanes.

12. A turbo-machine (40) comprising:

an airfoil (52,70) having a leading edge (60,76) disposed in a flow stream (90) passing through said turbo-machine (40);

an endwall (50,54,72) disposed adjacent an end of said airfoil (52,70), said flow stream (90) passing along said endwall (50,54,72) and over said leading edge (52,70); the flow of said flow stream (90) through said turbo-machine (40) and over said leading edge (52,70) generating a stagnated flow force, a radial equilibrium force, a centrifugal force, and a leading edge force;

a means (56,58,74) for generating a radial vector in said leading edge force of sufficient magnitude to prevent the creation of a horse-shoe vortex in said flow stream (90) as it passes over said leading edge (52,70), said generating means (56,58,74) being disposed at the intersection of said leading edge (60,76) and said endwall (50,54,72).

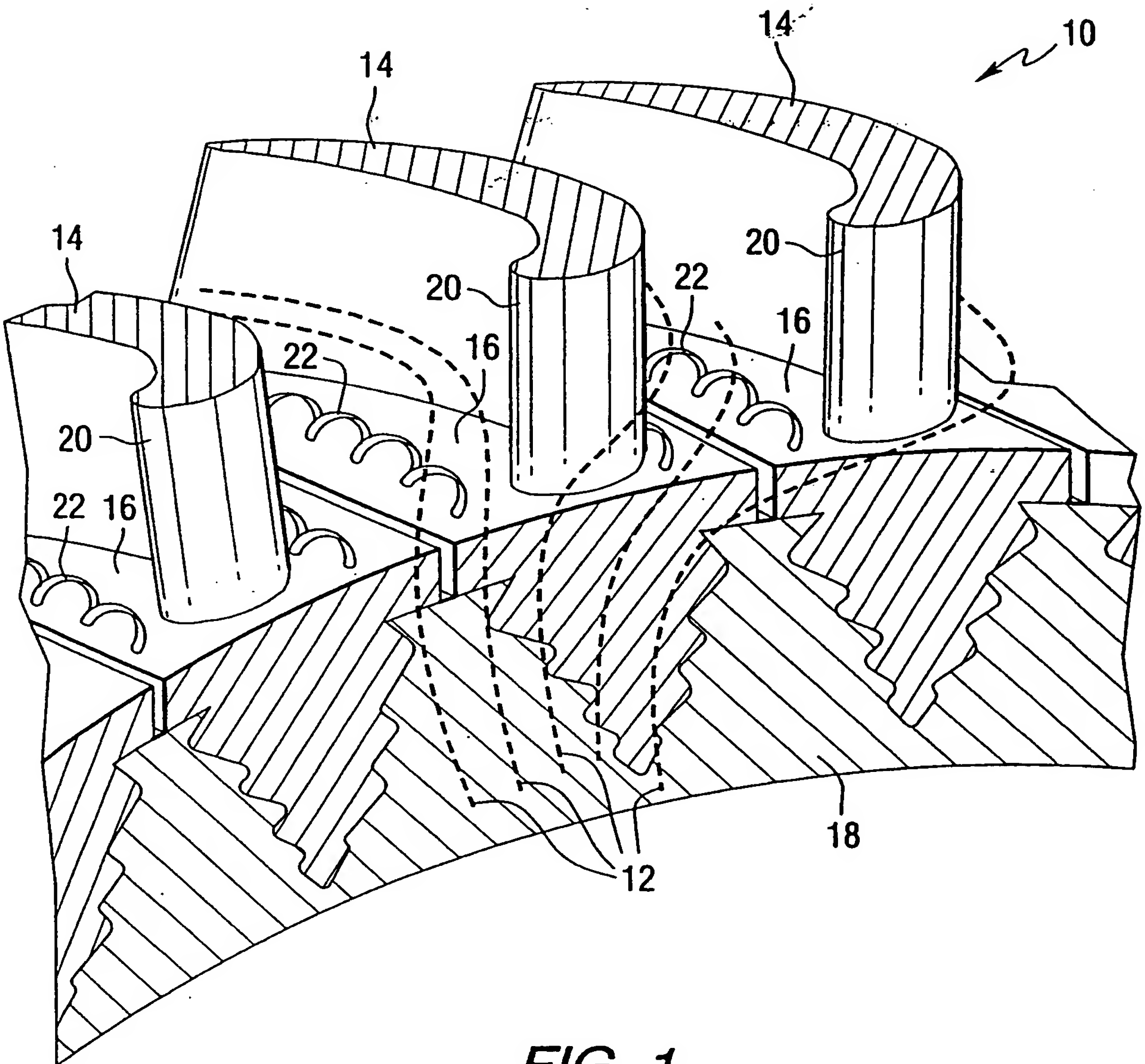

FIG. 1
PRIOR ART

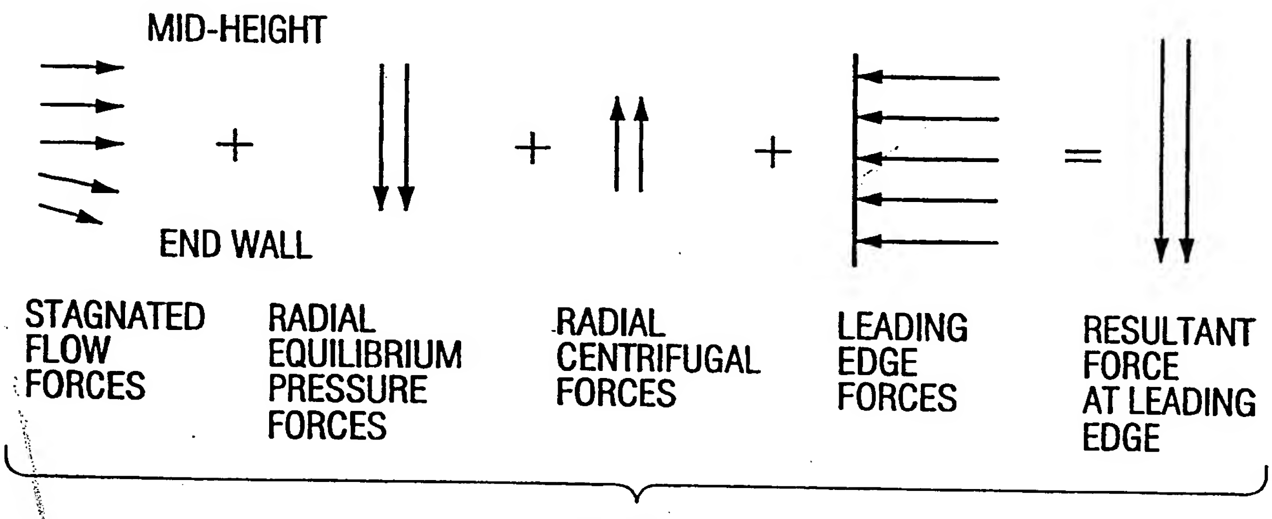

FIG. 2
PRIOR ART

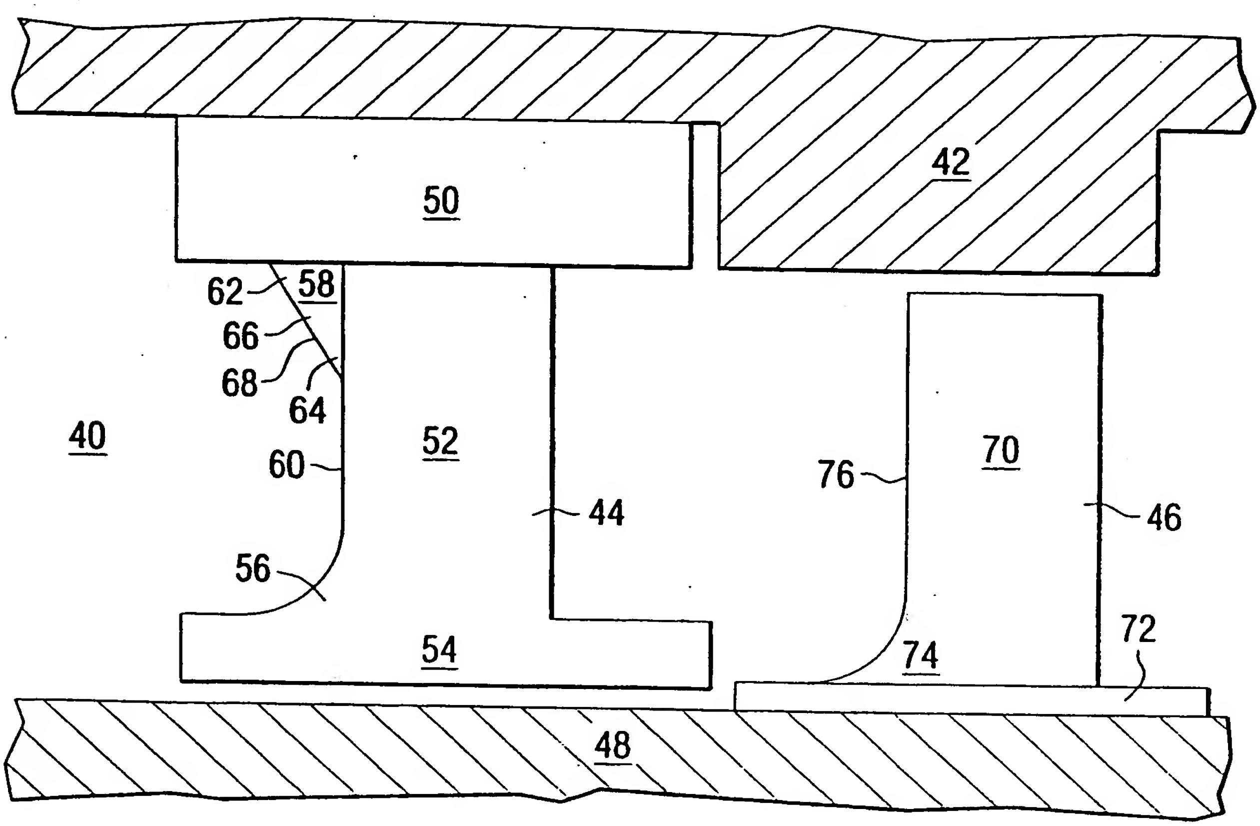

FIG. 4

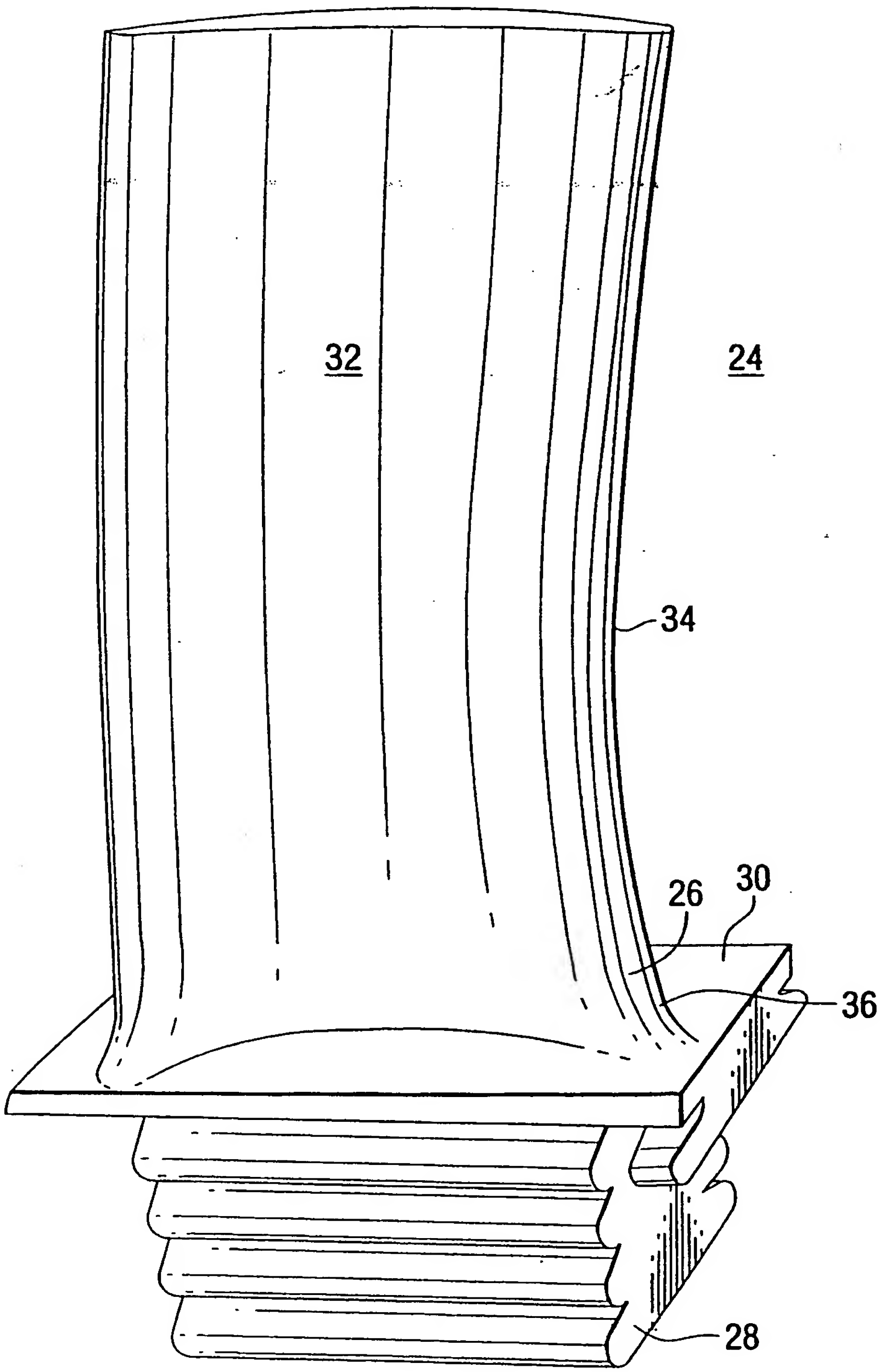

FIG. 3

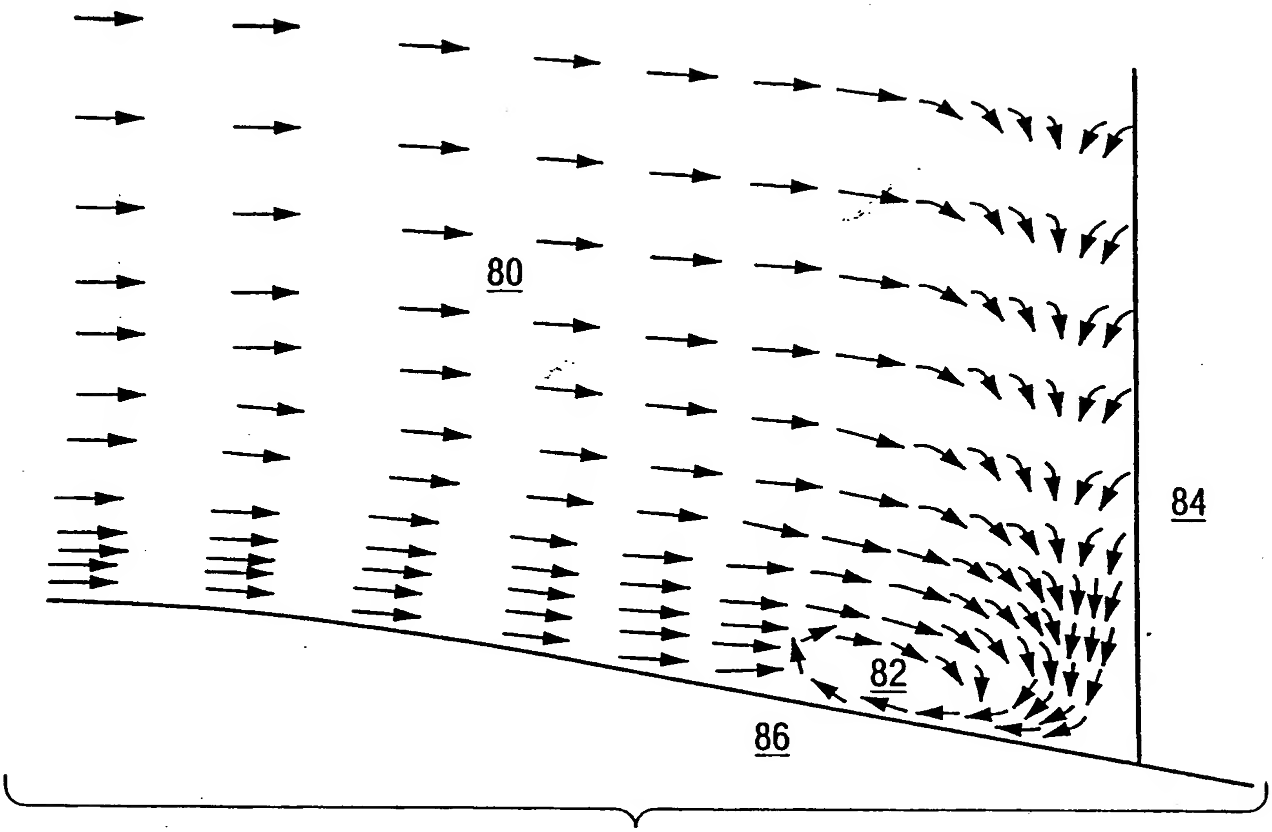

FIG. 5
PRIOR ART

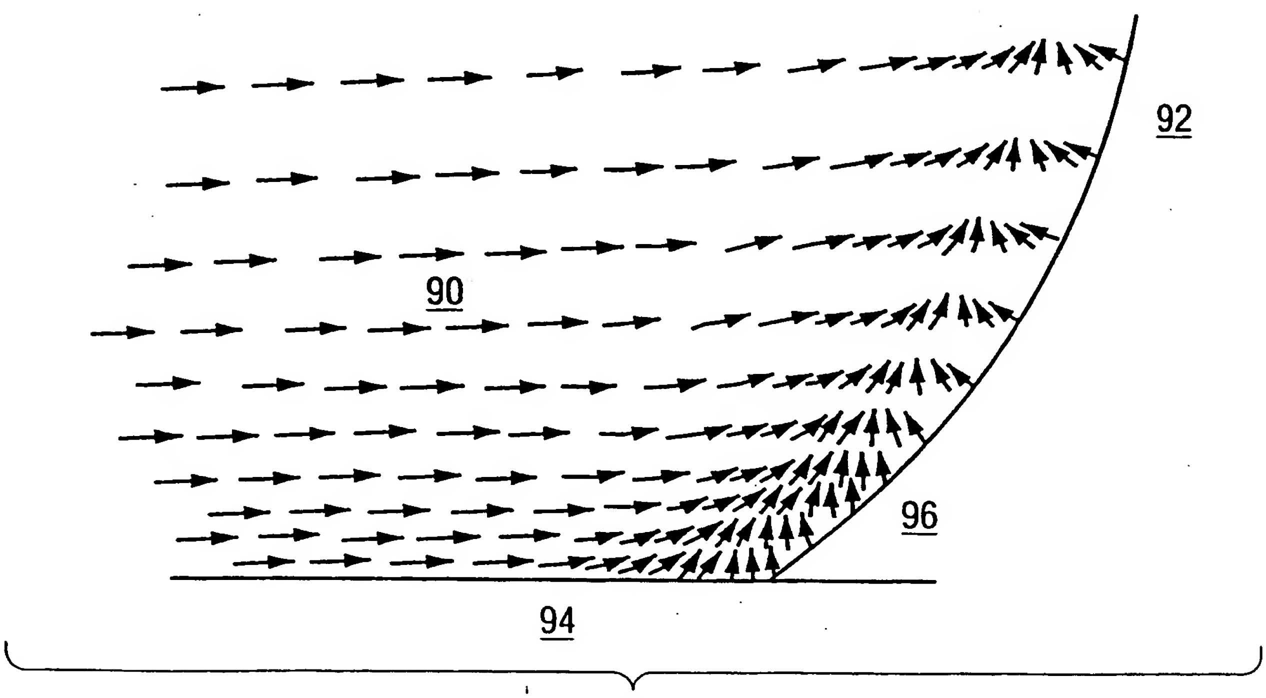

FIG. 6

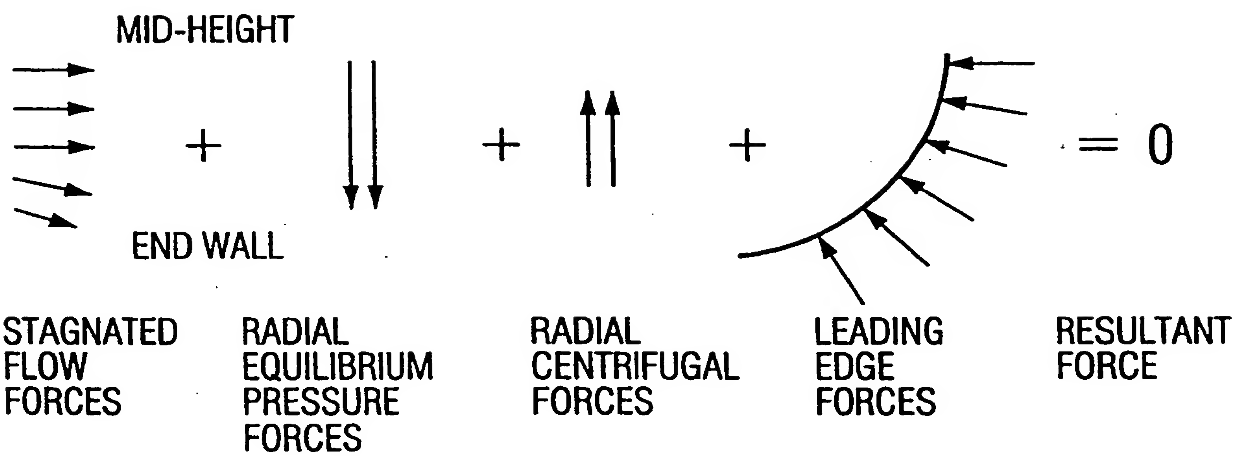
MID-HEIGHT
END WALL
+
+
+
= 0
STAGNATED FLOW FORCES
RADIAL EQUILIBRIUM PRESSURE FORCES
RADIAL CENTRIFUGAL FORCES
LEADING EDGE FORCES
RESULTANT FORCE

FIG. 7